CLIMATE CHANGE AND TEMPERATURES

Testimony of

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before

The U. S. Senate Committee on Commerce, Science, and Transportation
The United States Senate
SR-253 Russell Senate Office Building
9:30 a.m., May 17, 2000

[*] Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of the National Science Foundation.
[**] The National Center for Atmospheric Research (NCAR) is sponsored by the National Science Foundation.

Introduction

My name is Kevin Trenberth. I am the Head of the Climate Analysis Section at NCAR, the National Center for Atmospheric Research. I am especially interested in global-scale climate dynamics; the observations, processes and modeling of climate changes from interannual to centennial time scales. I have served on many national and international committees including National Research Council/National Academy of Science committees, panels and/or boards. I recently served on the National Research Council Panel on "Reconciling observations of global temperature change", whose report was published in January 2000. I co-chaired the international CLIVAR Scientific Steering Group of the World Climate Research Programme (WCRP) from 1996 to 1999 and I remain a member of that group as well as the Joint Scientific Committee that oversees the WCRP as a whole. CLIVAR is short for Climate Variability and Predictability and it deals with variability from El Niño to global warming. I have been involved in the global warming debate and I am extensively involved in the Intergovernmental Panel on Climate Change (IPCC) scientific assessment activity as a lead author of individual chapters, the Technical Summary and Policy Makers Summary of Working Group I.

During the past 20 years, global mean surface temperatures have been rising at a rate as large as any that has been observed within the historical record. Such rapid warming at the Earth's surface is in contrast to the trend in the global-mean temperature of the lowest 8 kilometers of the atmosphere (within that portion of the atmosphere referred to as the troposphere) as inferred from measurements of radiation emitted by oxygen molecules (a proxy for tropospheric temperature) sampled by the microwave sounding unit (MSU) carried aboard the NOAA polar-orbiting satellites; see Fig. 1 for the vertical structure of the atmosphere. I will summarize here the state of knowledge with regard to observed climate change, and especially the issues of the changes in temperatures as seen by the synthesis of observations taken at the Earth's surface versus those measured by satellite.

Observed climate change

It is important to appreciate that temperature changes are only a part of the total picture. Global warming refers to the increased heating of the Earth arising from well documented increases in greenhouse gases such as Carbon Dioxide. At the surface, some of that heat goes into raising temperatures, but most of it goes into evaporating moisture. This is especially true as long as the surface is wet, as it always is over the 70% of the globe covered by oceans. After rainfalls, in bright sunshine, it is only following the drying up of surface puddles that temperatures are apt to rise. Accordingly, the strongest heat waves occur in association with droughts because then there is no surface moisture to act as a "swamp cooler", and droughts are apt to become more intense with global warming. Meanwhile the increases in atmospheric moisture fuel more vigorous storms. Changes in extremes of climate will be much greater than changes in the mean. It also means that temperature increases are likely to be muted in places where precipitation has increased, as is generally the case for most of the United States. Changes in cloud cover, storm tracks, winds, and so forth further complicate the picture. The very nature of the atmospheric circulation, in which large-scale waves occur, also guarantees that some regions will warm more than others and some regions may cool even as the planet as a whole warms. These comments highlight the need to examine several factors, including precipitation, when developing an understanding of temperature changes.

Surface temperatures

The surface temperature record is made up mostly from measurements by thermometers that track surface air temperature over land and ocean, as well as sea surface temperatures (SSTs) over the oceans. In recent years satellite infrared measurements have helped determine patterns of SSTs. The coverage increases over time after about 1850; it was quite poor in the 1800s and is best after the 1950s. It is only truly global after 1982 with the help of satellite measurements. It is generally poor over the southern oceans and there were almost no data over Antarctica prior to the IGY (1957). Changing biases confound the climate record. These arise from changes in observing practices (thermometer types, their exposure, the time of measurement etc), and changes in land use practices. The urban heat island is the best known latter effect and arises because of the concrete jungle in cities which retains heat at night and causes rapid runoff of rain.

The advantages of the surface record are its length, well over 100 years, the many independent measurements, several independent analyses, and its robustness to the many cross checks, such as Northern versus Southern Hemisphere, urban versus rural, and land-based versus marine measurements. The disadvantages are the mostly less than global coverage, and coverage changes with time. An overall assessment is that the trends are robust, but may be slightly over-estimated owing to under-representation of the southern oceans and Antarctica.

Surface temperatures (Fig. 2) have increased by 0.7C (1.3F) over the past century. The increase is not steady but occurs mainly from the 1910s to 1940 and the 1970s to the present. 1998 is the warmest year on record and the 1990s are the warmest decade in both hemispheres, on land and on the ocean. Melting glaciers and rising sea level provide strong supporting evidence. However, over land nighttime temperatures are rising faster then daytime temperatures, by almost 0.1C per decade since 1950, apparently largely because of increases in low cloud cover.

The surface temperature record has been extended back in time by use of proxy indicators that are known to be sensitive to temperatures, such as from tree rings, corals, and ice cores. A recent synthesis of these provides further context for the recent trends and shows that the last decade is likely to have been the warmest in the past 1000 years.

Radiosonde temperatures

Measurements of temperatures in the atmosphere above the surface became routine beginning in the mid-1940s through use of balloon-borne instrument packages (radiosondes) that transmit thermister-measured temperatures back to ground along with pressure and humidity. Their purpose has been mainly for aviation use and weather forecasting. The observations are at best twice daily and while spatial coverage improved in the IGY, it is marginal for large-scale estimates before about 1964. The biases are the many changes in instrumentation and observing methods, often with poor documentation of these changes. There are known biases in some brands, and a common problem has been improper shading from the sun and adequate ventilation. [Recall the temperature is that of the air, which must therefore be circulated past the sensor, and the sensor must be protected from direct solar radiation.] The advantages are the very high vertical resolution of the measurements, the use of new independent instruments for each sounding and the diversity of instruments. Also, there have been a few independent analyses. The disadvantages are the diversity of instruments that are inadequately calibrated for climate purposes, their often unknown changes with time, and the spotty non-global coverage. An assessment suggests that the tropospheric record is reasonably well known after 1964 in the Northern Hemisphere extratropics, but that coverage is inadequate elsewhere.

Satellite temperature measurements

The satellite record is made up of MSU measurements of microwave radiation emitted by the atmosphere which are proportional to temperature. The coverage began in December 1978 twice or four times a day from one or two satellites, and is global. The emissions represent a very broad layer in the vertical, and so a retrieval is used to obtain the temperature closer to the surface. This is the commonly used satellite record but it still represents the lowest 8 km or so of the atmosphere, so it is physically a very different quantity than the surface temperature.

The observation times vary with satellite and orbit drift. Biases arise from the use of 9 different satellites and instruments, orbital decay affects the retrieval, east-west drift of the satellite affects the time of day of observation, and there are instrument calibration and solar heating of the platform effects. Another significant factor is that the retrieval amplifies the noise by a factor of 3 to 5. Other disadvantages are some contaminating effects from the surface, especially over land, contamination by precipitation-sized ice, the difficulty of obtaining continuity across satellites, the shortness of the record, and one group has processed the data. The advantages are the global fairly uniform coverage, the long-term stability of microwave radiation emissions from oxygen, the biases may be well determined if there is adequate satellite overlap, and there are many observations which can be used to reduce random noise. The assessment is that this record is excellent for spatial coverage and determining interannual variations but suspect for trends.

Reconciling temperature records

All three records have been improved and developed in recent years. In particular several corrections have been made to the satellite record (e.g., for orbital decay), and these have improved the agreement. Using the radiosonde record to estimate the temperatures of the layer seen by satellite shows very good agreement, so that the radiosonde record can be used to extend the satellite record back to about 1964 (Fig. 3). While tropospheric temperature trends from 1979 to 1999 are small, longer term trends are more clearly positive and closer to those at the surface.

It is evident that the trends in the satellite record are distinctly less than those in the surface record after 1979, and this arises primarily because they are measuring quite different things. The differences come from the vertical structure of the temperature changes with time, which are complicated by features, such as temperature inversions, in which the surface is disconnected from the atmosphere aloft. Low level inversions trap pollutants near the surface and are common over extratropical continents in winter, as well as throughout much of the tropics and subtropics. The physical forcing factors believed to be involved in causing differences in trends include (1) stratospheric ozone depletion which preferentially cools the satellite record; (2) episodic volcanic eruptions which cool the MSU more; (3) increases in greenhouse gases which warms MSU more; (4) changes in visible pollution (aerosols) which have complex regional effects that are not well known in vertical structure; (5) solar variations which are fairly small in this interval.

Other physical factors include (1) El Niño and other natural variability which seems to produce a larger MSU response than at the surface by about 30 to 40%; (2) day-night differences which relate to maximum versus minimum temperature trends; and (3) land-ocean differences. The much greater increases in minimum temperature, related to increasing cloud cover, occur through a shallow layer and are not seen as much by satellite as maximum temperature changes which are distributed throughout the atmosphere by convection. The extent to which the changes in cloud cover arise from changes in atmospheric pollution or are a response to climate change is quite uncertain. Also ocean surface temperatures are muted, land temperature changes are much larger, and these differences are paramount at the surface but less evident in the troposphere where winds are much stronger.

Not all of these effects have been included in models that deal with global warming or future climate change projections, but more sophisticated climate model simulations are expected in which best estimates of all the forcings will be included. Further improvements are also likely in the observational records of all three types. However, it is believed that the records are reasonably physically consistent with each other once all the forcing factors are taken into account. Accordingly, the recent warming at the surface is undoubtedly real, substantially greater than the average rate during the 20th century, and is in no way invalidated by the satellite record.

A reasonable interpretation of the observational record is that global warming from increased greenhouse gases is resulting in global temperatures that are now above and beyond those arising from natural variability. The main reasons tropospheric temperatures are not keeping pace are because of stratospheric ozone depletion and increases in cloud cover. Consequently larger surface temperature increases occur over land and at nighttime. While observationally uncertain globally, although with strong evidence over the United States, increases in surface drying, atmospheric moisture amounts and precipitation rates are expected as part of an increase in the hydrological cycle. This increases risk of floods, droughts and associated fires; these are all extremes which are very costly to the environment and to society.

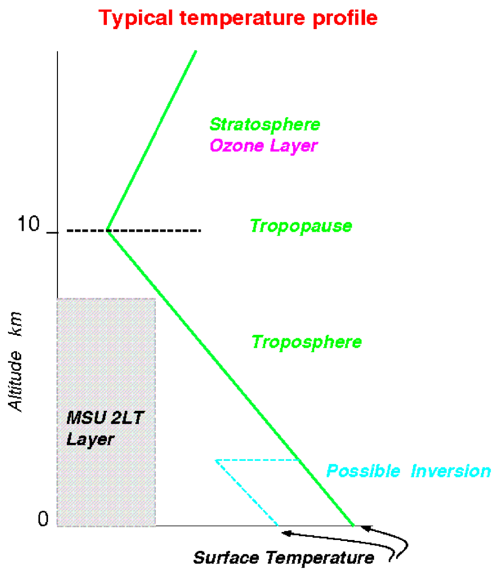

Fig. 1. The typical structure of temperature with height is shown. The lower atmosphere is the troposphere and the lowest 8 km or so of that is the region measured by the MSU-LT. The stratosphere contains the ozone layer and is separated from the troposphere by the tropopause which varies in height from about 10 km in the extratropics to 16 km in the tropics.

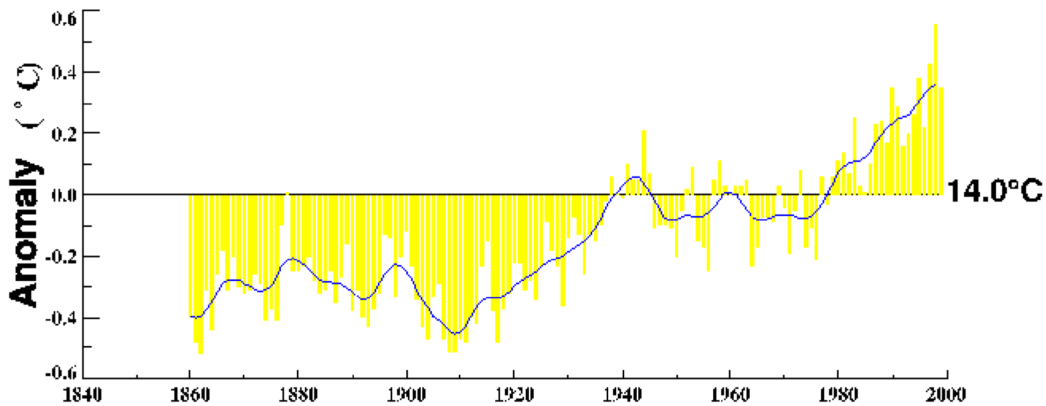

Fig. 2. The average annual mean global temperature expressed as the departure from the 1961-90 average of 14C, called anomalies. From U.K. Met. Office and University of East Anglia.

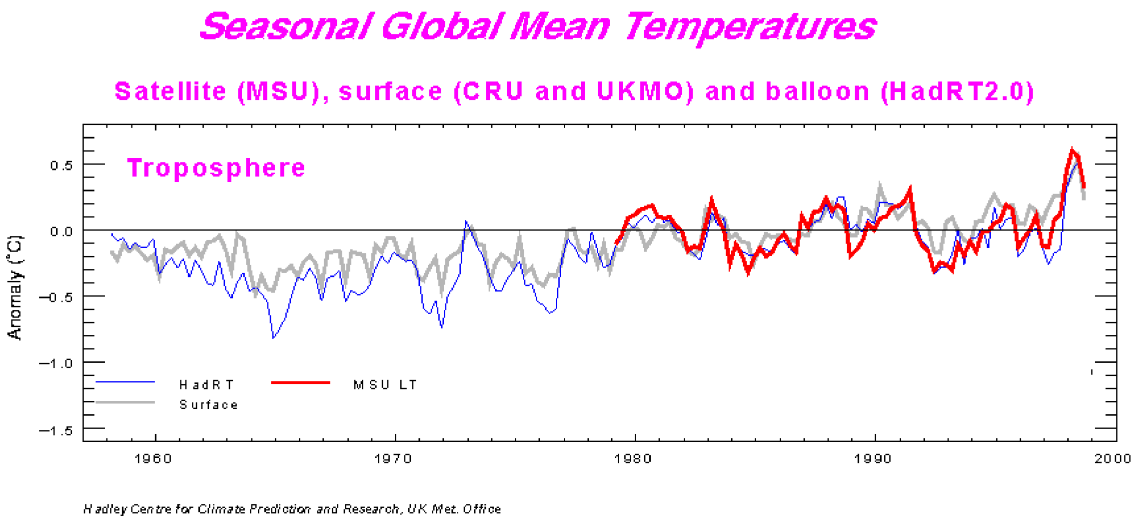

Fig. 3. Global mean seasonal temperature anomalies from the MSU-LT after 1979, the equivalent from radiosondes, and the surface from 1958 on.